Detecting Planet Transits

Trial edition of a Great Explorations in Math and Science (GEMS) activity developed with the NASA Kepler Mission Education and Public Outreach.

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Alan Gould

Grades 5-8

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The Kepler Spacecraft

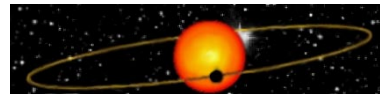
Great Explorations in Math and Science

Lawrence Hall of Science
University of California, Berkeley

DETECTING PLANET TRANSITS

We are interested in detecting and studying extrasolar planets as possible abodes for life. Since 1995, Jupiter-size planets have been found orbiting other stars, but we'd *really* like to find Earth-size planets. The key problem in detecting extrasolar planets is that the stars are so far away, and so bright compared to their planets, that we even begin to see the planets directly.

Transits to the rescue! What is a *transit*? If we see a planet cross in front of a star, the event is called a *transit*. NASA's Kepler mission is designed observe transits, allowing us to detect not only planets, but habitable Earth-size planets. This activity shows students how that will be done. By modeling planetary transits, students learn about one way that planets can be detected, what scientists can learn about planets discovered this way, and experience the power of models as a scientific tool.



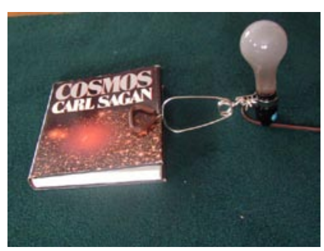
We say the planet is transiting *the star when it goes in front of the star.*

This activity may preceded by the activity *Habitable Planets*, so that students already know what the term *habitable* means before doing this activity on planet transits.

Materials

For the whole class:
1 stop watch or wall clock with a second hand

For each group of 3-5 students:
1 clamp-on light socket
2 light bulbs, 7.5 W and 25 W
1 black thread, 1-meter long
1 thin wooden dowel, 3-4 mm (or 1/8 in) diameter, 30 cm (1 ft) long [a chop stick would work]
1 long pipe cleaner 30 cm (1ft)
1 extension cord
several beads of various sizes, 2 mm to 2 cm
tape



A clamp-on socket, can be clamped onto the back of a chair or onto the cover of a sturdy hard copy book on a table.

Preparation

Have materials for each group in bags, a box, or on a tray ready to be handed out.

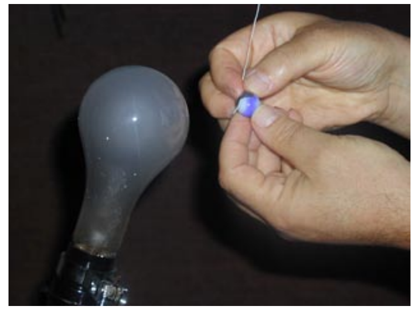
If any "orbiting" beads are heavy enough to constitute a risk of breaking a light bulb, safety goggles may be used.

To prepare for conducting this activity, you can visit the

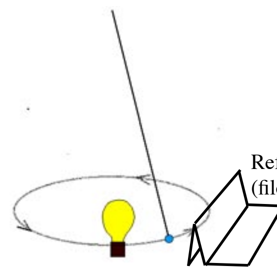
Kepler website— http://kepler.nasa.gov/ and the

Planet Quest site — http://planetquest.jpl.nasa.gov/

For whole class demonstration (step 8):



1. A light must be positioned either in the center of the room or at least a couple of meters away from a wall. Each student must be able to position his or her eye at the same height as the light, so the light must not be higher than the eye level of the shortest student standing up.
2. Tie or tape a bead, ball, or marble to a length of thread. To keep thread from tangling, it's a good idea to wrap them each around a small piece of cardboard, 3x5 card, or paper folded up into a "card."
3. Practice swinging the bead or marble in orbit around the light. It can be difficult to hold the string at a good height for the group to observe transits. It helps to place a reference object, such as a file folder, appropriately folded and taped, just outside the orbit path, about 2 or 3 feet away from the light, and at the same height as the light. You can aim for that reference point to get the orbit of the planet at the same level as the light.



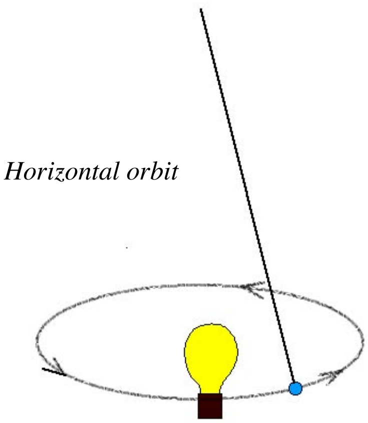
➔Go

1. Ask the class: How might we go about detecting life outside our solar system?" [Possible answers: detect radio signals from advanced civilizations, send a spacecraft to explore the planet] If they mention detecting radio signals, mention that people are trying that, but it's hard since we don't know where the signals would be coming from or what frequency would be used. If they mention exploring a planet with a spacecraft, say that we've been doing that for the planets in our solar system, but planets around other stars are too far away to explore with a spacecraft. It would take thousands of years for a spacecraft to get there.

2. Planets around other stars. Ask "Why might it be difficult to detect a planet going around a star other than the Sun?" [The planets are too small to be seen. The stars are too far away and the planets too small. The star is too bright and the planet too dim. The planet is lost in the glare of the starlight.] Ask: "How might we find a planet in orbit around another star?" If a student suggests just looking through a telescope, point out that planets are very dim and are normally not visible in the glare from the star. If a student suggests detecting motion of the star from the planet's gravity, acknowledge that that is indeed a good method, and many planets have already been discovered that way. If no one suggests anything like observing a transit, ask: "What might we observe if a planet passed between us and its star?"

3. Transits. Explain that when a planet crosses in front of its star, the event is called a "transit" and that transits can enable us to learn about extrasolar planets—planets orbiting other stars. Ask: "What are some things that people might want to learn about a planet?" [Possible answers: the planet's size, mass, chemical makeup, size of its orbit, orbital period] Explain that scientists often use models to help them learn about something and that the class will be constructing models of a transits." Tell them that they will work in groups with some simple materials to make models of transits: planets orbiting other stars.

4. Making model transits. Divide the class into groups of 3-5 people, distribute a set of transit modeling materials to each group, and explain that when scientists start an investigation, there is no one to hand them a step-by-step procedure explaining what to do. Challenge them to make a model of a transit with the materials at hand. Give them five minutes to examine the materials and discuss within their groups how they might make a model of a transit. [Possibilities include suspending a planet from the thread or attaching it to the dowel or pipe cleaner. The various options allow the groups to make different types of models and later discuss the pros and cons of their methods.]



Safety Tip: Tell the students that light bulbs get hot, so don't touch them after they're turned on.

5. Circulate and help as needed. If a group seems to have trouble getting started, provide some guidance by asking questions, such as: "What kinds of astronomical objects will be part of your model?" [A star and a planet.] "What might you use to model the star?" [The light bulb, because it's big and bright.] "What might you use to model the planet?" [One of the beads.] "Will anything in the model move?" [The planet orbits around the star.] "Which of your materials could you use to show the planet orbiting around the star?" [The planet (bead) could be suspended from the thread or attached to the dowel or pipe cleaner.]

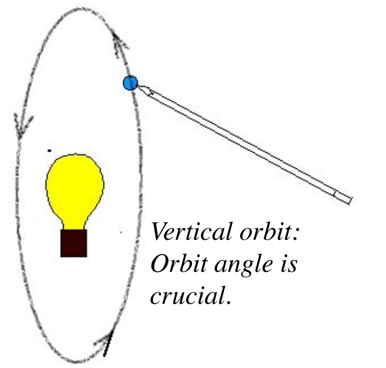
6. Varying parameters. If some groups seems to have finished exploring with their models before others, suggest that they try varying certain parameters. For instance, say: "How would the transit look different with a different size planet?" "How would it look different with a star having a different brightness?" "Does the distance of the planet from the star make a difference?" "Does the viewing distance or angle make a difference?"

7. Demonstrating the models. After all groups have spent some time using their models to investigate transits, have presentations to the whole class. Ask one representative from each group to describe that group's model, what features they included, what parameters were varied, and any interesting tidbits about it.

8. Summarizing what a transit model tells us. Point out how models are powerful tools to visualize and investigate various phenomena. Different models can demonstrate different things. No single model demonstrates everything, but it doesn't need to in order for us to learn from it. Set up a transit model in the center of the room and have students arrange themselves in a semicircle around the light so that they each have an unobstructed view of the light. Optional: darken the room for dramatic effect. Start a large bead or marble in orbit around the light bulb. Ask, "What does the word *orbit* mean?" [The model planet is orbits the model star.] Have students raise their hands if they see the planet go directly in front the light—not above it or below it, but actually blocking the light. When all the studnets are doing this right, they will be creating a "wave." Ask students, "What do you have to do to see a transit? [Students are different heights. To see a transit, your eye has to be directly in line with the planet and star.]

9. Variables in the model. Ask students what variables there are in the model—what things can change? Make sure that the following are noted:

a. Angle of observation. Point out that orbit angle is crucial Have people move their heads up and down to see different viewing angles while the planet orbits. If none of the groups have demonstrated a vertical orbit, tape a bead onto a stick or pencil and move it in a *vertical* orbit around the light bulb. If you do this, and ask students to raise their hands if they see a transit, probably only two people will see them—those who are in the plane of the orbit. Ask, "Would we be able to see transits of planets in all planetary systems?" [No.] Why not? [We can only see the transit of a planet when the planet passes directly between the star and us as it orbits the stars.]



Vertical orbit: Orbit angle is crucial.

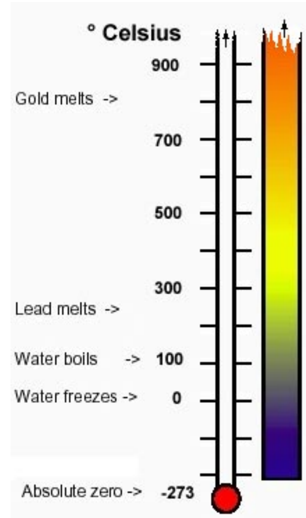
b. Glare. Ask the students, "Does the glare of the light bother you? Does it makes it hard to see the model planet?" Emphasize that this is the main thing that makes it very hard to find planets around other stars—stars are more than trillion times brighter than any planets orbiting them.

c. Size. Ask "How much harder is it to see a really small planet?"

d. Period. To alter the period of the planet, change the length of the pendulum thread. Optional: time the period with a stopwatch or clock, having a student say "Transit" (or some other indicator sound) every time they see a transit. Explain that a planet's *period* is the time it takes the planet to make ***one*** orbit. Define an accelerated time with 1 second = 1 month for our model. Start the planet orbiting and the first time the student calls out "transit," stop and ask, "Do we know the period of the planet's orbit now?" [Not really.] Make sure everyone realizes that observing one transit cannot give us the period, since we do not have a "start time" to compare with. Also, something other than a planet, not in orbit, might pass in front of the star. Ask, "What do we have to do to know the period of the planet?" [Observe 2 or more transits and measure time BETWEEN transits.] Find out how many days (months or years) the period is using 1 sec = 1 month.

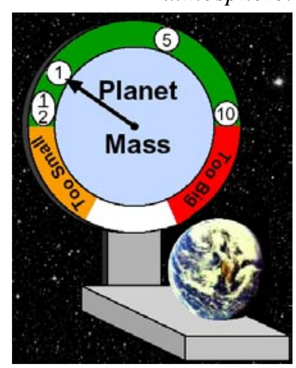
Optional: Simulate observing through a telescope. Have students use their hands: curl their fingers into "tubes", one hand in front of the other, and hold them up to one eye as a "telescope". [They could also roll up a sheet of paper into a tube to look through as a fake telescope.] This limits the view to only the "star" and the region immediately around it. Explain that real telescopes have lenses and sometimes mirrors that make things look much bigger and brighter. Have students observations the transits, but this time they look through their fake "telescopes." Is it easier or harder to see the transit when the field of view is limited?

9. The NASA Kepler mission. Tell the students that in 2008, NASA's Kepler mission will be launched. The mission is designed to detect habitable planets. Lead a discussion that gives the students insights into the Kepler mission through a series of questions:



A habitable planet needs the right temperature—for liquid water...

...and the right size to have suitable atmosphere!



- Ask them what *habitable* means. [A planet that could harbor life is called a habitable planet.

- "Just what makes a planet habitable?" [In a nutshell: liquid water**.** Just about all life that we know of on Earth has liquid water as an essential ingredient and liquid water is one of the only ingredients that nearly everyone agrees is essential for life. For a planet to have liquid water, it has to have a temperature between the freezing point and boiling point of water.
  For very large (Jupiter-size) planets it's possible to measure the drop in brightness using a telescope on Earth. But to detect Earth-size planets by observing transits, a telescope in space is needed—hence the need for the NASA Kepler mission: a telescope in space that will detect planet transits.

- "From our transit models, can you tell how the NASA *Kepler* mission is able to find Earth-size, habitable planets?"

- "How can observation of transits tell us about the size of a planet?" [Kepler scientists will be able to tell the size of a planet by carefully measuring the drop in brightness of the star during the transit—bigger planets block more starlight and cause a bigger drop in brightness. Kepler is poised to find planets 30 to 600 times less massive than Jupiter.]

- "How does the size of the planet affect it's habitability?" [Planet size determines its atmosphere**.** It is a lot more likely that life will develop on a planet with atmosphere than one without atmosphere. To have an atmosphere, a planet must be big enough to have the gravity needed to keep gases from just flying off into space. If the planet is too large, it is a giant, with nearly ***all*** atmosphere.]

- "How do you think the period of the planet is related to its distance from its star? [The time interval between transits tells us how long the planet takes to revolve around the star, i.e., the planet's orbital period. Since the planet's orbital period is related to its distance from the star (Kepler's 3rd law of planetary motion), we can also derive the planet's distance from the star.]

- "How does the planet's distance from its star affect its habitability?" [Distance from the star determines the temperature, and the possibility that liquid water is there.]

Conclusion: The *Kepler* mission will enable us to find habitable planets around other stars!

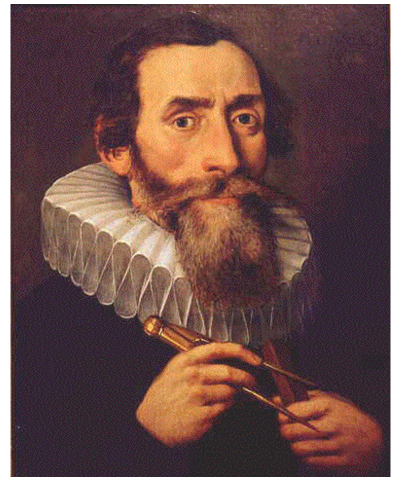
OPTIONAL

Some students may ask how knowing the planet's period can tell us the distance of the planet from its star. Distance from the star can be computed using Kepler's 3rd law, which relates the period of a planet's orbit, with the diameter of the planet's orbit. There can be a whole other activity that teaches Kepler's 3rd law, but the essence of Kepler's 3rd Law is expressed
(a) qualitatively in that the farther away a planet is from its star, the longer it takes to go around the star, and
(b) mathematically (quantitatively) by

$$\frac{R^3}{P^2} = \text{Constant}$$

Note: Planet orbits are elliptical, so when we refer to radius here, we really mean the average distance of the planet to the star.

Where
P = Period in Earth years
R = Orbit radius in Earth orbit radii (AU)
[One Earth orbit radius = one Astronomical Unit = 1 AU]



Johannes Kepler

The constant is actually 1 $AU^3/year^2$ for the solar system.
So for Earth:

$$\frac{(1\ AU)^3}{(1\ year)^2} = 1\ (AU^3/year^2)$$

Going Further

1. An algebra activity about Kepler's Law can be done with the solar system as a model. Make a chart showing the planets in our solar system and their respective orbit periods and orbit radii. Students try to find a formula to relate period and orbit radius. Groups may try different formulae by making tables. Spreadsheet program such as Excel can make this very easy.

2. Measure the transit drop in brightness of a model planet. Using a model star (light bulb) and some different size model planets (disks of cardboard or heavy paper), see if you can detect a drop in brightness using some sort of light meter or brightness measuring device. Professional light meters can cost hundreds of dollars, but you can use a solar cell and multimeter for under $20 from an electronics store.

Sample Trial formula: D/P = Constant? [No.]

Solar System Data

Orbit radius		Period (P)	D/P
	AU	(years)	AU/P
Mercury	0.4	0.2	1.625
Venus	0.7	0.6	1.1613
Earth	1.0	1.0	1
Mars	1.5	1.9	0.8085
Jupiter	5.2	11.9	0.4384
Saturn	9.5	29.5	0.3238
Uranus	19.2	84.0	0.2286
Neptune	30.1	165.0	0.1824
Pluto	39.4	248.0	0.1589

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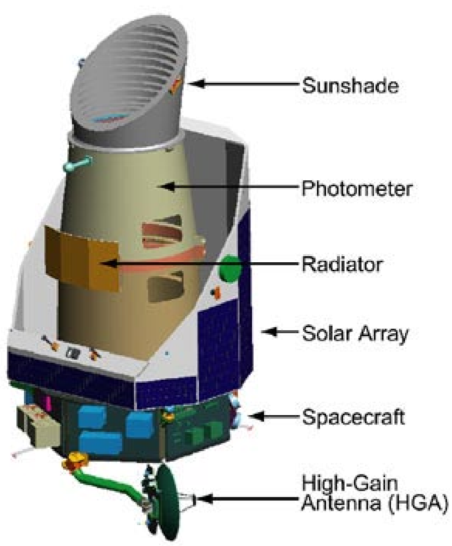
National Standards

5-8: Science as Inquiry, Content Standard A: Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.

9-12: Science as Inquiry, Content Standard A: Formulate and revise scientific explanations and models using logic and evidence. Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical.



The Kepler Spacecraft

The Kepler satellite has a 0.95-meter diameter telescope with a photometer that has a field of view that is square of sky that a bit over 10 degrees on each side (about a hand's-width). It is designed to continuously and simultaneously monitors brightnesses of 100,000 stars in the constellation Cygnus brighter than 14th magnitude.

To detect an Earth-size planet, the photometer must be able to sense a drop in brightness of only 1/100 of a percent. This is akin to sensing the drop in brightness of a car's headlight when a gnat flies in front of it! The photometer must be spacebased to obtain this precision.

The Kepler telescope must be in space because ground-based observing has two intrinsic limitations:

(a) The motions in the atmosphere are constantly bending the rays of light from each star into different directions changing the apparent brightness by more than 50%. This is why stars appear to twinkle. Planet transits cause change in brightness of less than a 1/10 of a percent.

(b) To detect a planetary transit as short as 2 hours out of a year requires measuring the brightness of the stars continuously. You can't blink! Earth-based telescopes can only do observations at night and when there is no bad weather.

